

The Senate Interim Committee on Natural Resources



Interim Report to the 78th Legislature

*Opportunities for Alternative Fuels and Fuel
Additives: Technologies for Converting Waste into
Fuel*

August 2002

Senate Interim Committee on Natural Resources
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Opportunities for Alternative Fuels and Fuel Additives: Technology to Convert
Existing Waste into Tomorrow's Fuel

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Necessity first mothered invention.
Now invention has little ones of her own,
and they look just like grandma. E.B. White¹

INTRODUCTION

In the last few decades, we have recognized new “needs” as we discuss what we want from the way we produce and use fuel in Texas. Alternative fuels has been brought to the table as a potential solution to problems in issues as diverse as air quality, national security, water quality, waste disposal, and rural development. In each case, the solutions are inextricably intertwined with the technology that produces newer kinds of energy. As our country has come to grips with 21st century challenges, it has become clear that studying alternative fuels forces us to consider energy policy as part of a greater whole.

Because the charge is focused on alternative fuels from wastes, this report will cover topics relating to ethanol, which can be made from agricultural waste, anaerobic digesters, which can collect methane gas from animal wastes into a usable fuel stream, biomass technologies, which can put to use any waste vegetation, landfill gas collection systems, and the gravity pressure vessel, which turns any waste into ethanol.

These technologies offer a means to manage wastes or waste by-products which would have to be processed anyway. They also can creatively convert a waste stream into a renewable fuel. Not only do waste-to-energy programs solve energy and waste issues, they can improve air and water quality problems, and as previously

¹E.B. White In Writings from the New Yorker 1927-1976, ed. Rebecca M. Dale (1991). ““The Old and the New,”” New Yorker (June 19, 1937).

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mentioned, can act as drivers in development. Waste-to-energy programs have the potential to solve a myriad of problems and save money at the same time.

INTERIM CHARGE

Study and make recommendations on the research and use of alternative fuels and fuel additives in Texas. The Committee shall assess the cost-benefit of innovative technology in converting solid and agricultural waste into fuel and fuel additives.

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ETHANOL

We have a recent legislative history of interest in producing ethanol in this state. However, at the time of writing this report, we see that a deeper exploration of the issues surrounding the production of ethanol in Texas is being pursued elsewhere. The State Energy

Conservation Office is conducting a study on the feasibility of creating an ethanol industry in Texas. Furthermore on the national front, H.R. 4, the Energy Policy Act of 2002 is being considered by conference committee. Here, we have attempted a brief summary of issues surrounding ethanol, as we acknowledge the difficulty in forecasting what will come of the negotiations. If a bill does emerge, there is potential that it will significantly impact ethanol production.

Ethanol is an alcohol-based alternative fuel produced by fermenting and distilling starch crops that have been converted into simple sugars.

Joseph DiPardo's study entitled, "Outlook for Biomass Ethanol Production and Demand" addresses many of our interests.

Ethanol has been used as fuel in the United States since at least 1908. Ethanol production in the United States grew from 175 million gallons in 1980 to 1.4 billion gallons in 1998, with support from Federal and State ethanol tax subsidies and the mandated use of high-oxygen gasolines. In March 1999, Governor Gray Davis announced a phase out of the use of MTBE in gasoline by 2002 in California, which uses 25 percent of the global production of MTBE. [However, in March, Governor Davis postponed that ban by a year, stating, that the current production, transportation and distribution of ethanol is insufficient to allow California to meet federal requirements and eliminate use of MTBE on Jan. 1, 2003.²] It is unclear, however, whether the U.S. Congress will eliminate

² Schoch, Deborah and Morain, Dan. "Davis Delays Ban of MTBE" Los Angeles Times. March 14, 2002. <<http://www.grac.org/LATimesArticle.pdf>>

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the minimum oxygen requirement in reformulated gasoline (RFG), an action that would reduce the need for ethanol

At present, extending the volume of conventional gasoline is a significant end use for ethanol, as is its use as an oxygenate. To succeed in these markets, the cost of ethanol must be close to the wholesale price of gasoline, currently made possible by the Federal ethanol subsidy; however, the subsidy is due to expire in 2007, and although the incentive has been extended in the past, in order for ethanol to compete on its own merits the cost of producing it must be reduced substantially.

. . .

Background

Interest in ethanol was renewed in the 1970s, when oil supply disruptions in the Middle East became a national security issue and America began to phase out lead (an octane booster) from gasoline. The American Oil Company and several other major oil companies began to market ethanol as a gasoline volume extender and as an octane booster. Ethanol was blended directly into gasoline in a mix of 10 percent ethanol and 90 percent gasoline, called gasohol. In 1978, Congress approved the National Energy Act, which included a Federal tax exemption for gasoline containing 10 percent alcohol.³ The Federal subsidy reduced the cost of ethanol to around the wholesale price of gasoline, making it economically viable as a gasoline blending component. The growth of ethanol was enhanced substantially by State tax incentives to ethanol producers. By 1980, 25 States had exempted ethanol from all or part of their gasoline excise taxes in order to promote consumption. Ethanol production jumped from just over 10 million

³ At various times, different alcohols (e.g., methanol, isopropyl alcohol, and tertiary-butyl alcohol - TBA) exhibited commercial interest for gasoline blending because of market conditions or special performance properties.

Oxygenated Fuels Association. "What is MTBE and why is it used?" <<http://www.ofa.net/whatmtbe.htm>>

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gallons in 1979 to 175 million gallons in 1980. Federal and State tax incentives made ethanol economically attractive in the Midwest, but the difficulty and high cost of transporting ethanol precluded consumption in other markets

Currently, fuels blended with ethanol cannot be shipped in multifuel pipelines, because the moisture in pipelines and storage tanks is absorbed by the ethanol, causing it to separate from gasoline. Rather, the petroleum-based gasoline components have to be shipped separately and then blended with ethanol at a terminal as the product is loaded into trucks.

The ethanol program received a boost from Congress in 1990 with the passage of the Clean Air Act Amendments. Congress mandated the use of oxygenated fuels (with a minimum of 2.7 percent oxygen by volume) in specific regions of the United States during the winter months to reduce carbon monoxide. The two most common methods to increase the oxygen level of gasoline are blending with MTBE and blending with ethanol. Because ethanol has a higher oxygen content than MTBE, only about half the volume is required to produce the same oxygen level in gasoline. This allows ethanol, typically more expensive than MTBE, to compete favorably with MTBE for the wintertime oxygenate market. . . . Ethanol's high volatility, measured by Reid vapor pressure (RVP), limits its use in hot weather, where evaporative emissions can contribute to ozone formation. . . .⁴

Although most ethanol consumption is in conventional gasoline engines, which are limited to a 10-percent ethanol blend (E10), there is also

⁴ To burn properly in an internal combustion engine, the fuel must be well vaporized. The higher a fuel's volatility, the greater its level of evaporative emissions. If volatility is too low, there can be starting problems at low outside temperatures; if too high, there can be premature vaporization, particularly in hot weather, causing engine stalling. The Reid Vapor Pressure (RVP) is the measure of the fuel's vapor pressure at 37.8 degrees C, and is an important measurement of volatility.

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some demand for ethanol blended in higher concentrations, such as E85 (85 percent ethanol, 15 percent gasoline). E85 vehicles are currently in use as government fleet vehicles, flexible-fuel passenger vehicles, and urban transit buses.⁵ Demand for ethanol in E85 has grown from 144,000 gallons in 1992 to 2 million gallons in 1998. Most E85 use falls under government mandates to use alternative fuels.

Ethanol does not compete directly with gasoline, even at comparable costs, because its energy (Btu) content is lower than that of gasoline. It takes approximately 1.5 gallons of ethanol to deliver the same mileage as 1 gallon of gasoline.

MTBE (in addition to its use in high oxygen fuels) is widely used as a year-round gasoline additive for reformulated gasoline to meet the legislated requirement for 2.0 percent oxygen by weight. . . . In 1999, concerns about water quality resulted in the announcement of a State-wide phase out of MTBE by the Governor of California, as well as numerous legislative proposals at both the State and Federal levels aimed at reducing or eliminating the use of MTBE in gasoline. Ethanol would be the leading candidate to replace MTBE, although it is not without its drawbacks. . . .

Ethanol relies heavily on Federal and State subsidies to remain economically viable as a gasoline blending component. The current Federal subsidy, at 54 cents per gallon, makes it possible for ethanol to compete as a gasoline additive.⁶ Corn prices are the dominant cost

⁵ But mainstream auto makers are manufacturing flexible fuel vehicles, which can run on gasoline, E-10, E-85, or any blend of those fuels. Flexible fueled vehicles (also called variable fuel vehicles) have been produced by Ford (Ranger, Crown Victoria and Taurus), GM (Chevy S-10 and GMC Sonoma), and Daimler-Chrysler (Plymouth Voyager and Dodge Caravan).

U.S. Department of Energy. "Flex-fuel Vehicles." <<http://www.fueleconomy.gov/feg/flextech.shtml>>

⁶ This is an anecdotal account of how the subsidy works in practice: "The federal subsidy is a blender's tax credit of \$0.54 per gallon of ethanol. The subsidy is not paid directly to those who produce the ethanol. Rather, it accrues to the business or company that blends ethanol with gasoline. For example, each gallon of ethanol blended with gasoline by a petroleum distributor or retailer results in a \$0.54 income

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factor in ethanol production, and ethanol supply is extremely sensitive to corn prices, as was seen in 1996. Ethanol production dropped sharply in mid-1996, when late planting due to wet conditions resulted in short corn supplies and higher prices.

Substantial reductions in ethanol production costs may be made possible by replacing corn with less expensive cellulose-based feedstocks. Cellulosic feedstocks include agricultural wastes, grasses and woods, and other low-value biomass such as municipal waste.

tax credit from the tax owed to the federal government. If that company has an income tax obligation, the credit can benefit them directly. If they have no income tax obligation that year, the \$0.54 per gallon credit cannot be used and is of no benefit.

In reality, the subsidy is divided between the ethanol producer and the blender by altering the ethanol price based on ethanol demand relative to supply. If the supply of ethanol is high relative to the demand for it, the bulk of the subsidy will be kept by the blender. Or, as ethanol supplies become tighter, the ethanol producer can demand a higher price and a larger portion of the subsidy. "

Van Dyne, Donald L. "Federal Ethanol Subsidies: Status and Benefits"
<<http://www.ssu.missouri.edu/publications/policy/1997/vandyne.htm>>

Currently, motor fuels consisting of at least 10 percent biomass-derived ethanol are exempt from 5.4 cents of the 18.4-cents-per-gallon federal excise tax. The exemption is also available at lower rates per gallon of fuel for blends that are at least 7.7 percent or 5.7 percent ethanol. For all of these fuel blends, the exemptions provide a subsidy of 54 cents per gallon of ethanol used. In addition to the partial excise tax exemption, there are 3 income tax credits available for motor fuels containing biomass alcohol. In lieu of the excise tax exemption, an equivalent federal blender's income tax credit is available to fuel distributors that blend ethanol with gasoline.

Also available are a credit for pure alcohol fuels, which is typically available to retailers, and a small ethanol producer's credit. However, the partial excise tax exemption has been much more important than the income tax credits in terms of the amount of tax benefits claimed. The exemption for ethanol fuel was extended to fuel blends containing smaller amounts of ethanol in the Energy Policy Act of 1992. The 1998 Transportation Equity Act for the 21st Century extended the exemption through September 30, 2007. The act also reduced the rate of exemption from 5.4 cents per gallon of gasoline to 5.3 cents for the years 2001 and 2002, 5.2 cents for the years 2003 and 2004, and 5.1 cents for the years 2005 through 2007.

U.S. General Accounting Office. GAO/RCED-00-301R Tax Incentives for Petroleum and Ethanol Fuels
<<http://www.gao.gov/new.items/rc00301r.pdf>>

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Although cellulosic materials are less expensive than corn, they are more costly to convert to ethanol because of the extensive processing required.

Feedstock

A large variety of feedstocks are currently available for producing ethanol from cellulosic biomass. The materials being considered can be categorized as agricultural waste, forest residue, MSW, and energy crops. Agricultural waste available for ethanol conversion includes crop residues such as wheat straw, corn stover (leaves, stalks, and cobs), rice straw, and bagasse (sugar cane waste). Forestry waste includes underutilized wood and logging residues; rough, rotten, and salvable dead wood; and excess saplings and small trees. MSW contains some cellulosic materials, such as paper. Energy crops, developed and grown specifically for fuel, include fast-growing trees, shrubs, and grasses such as hybrid poplars, willows, and switchgrass.

Although the choice of feedstock for ethanol conversion is largely a cost issue, feedstock selection has also focused on environmental issues. Materials normally targeted for disposal include forest thinnings collected as part of an effort to improve forest health, MSW, and certain agricultural residues, such as rice straw. Although forest residues are not large in volume, they represent an opportunity to decrease the fire hazard associated with the dead wood present in many National Forests. Small quantities of forest thinnings can be collected at relatively low cost, but collection costs rise rapidly as quantities increase

Agricultural residues, in particular corn stover, represent a tremendous resource base for biomass ethanol production. Agricultural residues, in the long term, would be the sources of biomass that could support substantial growth of the ethanol industry. At conversion yields of around 60 to 100 gallons per dry ton, the available corn stover inventory would be sufficient to support 7 to 12 billion gallons of ethanol production per year, as compared with approximately 1.4 billion gallons of ethanol production from corn in 1998. However, the U.S. Department

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of Agriculture (USDA) and other appropriate entities must undertake rigorous research on the environmental effects of large-scale removal of crop residues. The cost of agricultural residues is not nearly as sensitive to supply as is the cost of forest residues, although the availability of corn stover could be affected by a poor crop year. The relatively low rise in cost as a function of feedstock use is due to the relatively high density of material available that does not involve competition for farmland. In addition, the feedstock is located in the corn-processing belt, an area that has an established infrastructure for collecting and transporting agricultural materials. It is also located near existing grain ethanol plants, which could be expanded to produce ethanol from stover. Initially, locally available labor and residue collection equipment might have to be supplemented with labor and equipment brought in from other locations for residue harvesting and storage operations, if the plants involved are of sufficient scale. Eventually, however, when the local collection infrastructure has been built up, costs would come down.

Dedicated energy crops such as switchgrass, hybrid willow, and hybrid poplar are another long-term feedstock option. Switchgrass is grown on a 10-year crop rotation basis, and harvest can begin in year 1 in some locations and year 2 in others. Willows require a 22-year rotation, with the first harvest in year 4 and subsequent harvests every 3 years thereafter. Hybrid poplar requires 6 years to reach harvest age in the Pacific Northwest, 8 years in the Southeast, Southern Plains, and South Central regions, and 10 years in the Corn Belt, Lake States, Northeast and Northern Plains regions. Thus, if it were planted in the spring of 2000, switchgrass could be harvested in 2000 or 2001, willow could be harvested in 2004, and poplars could be harvested in 2006, 2008, or 2010, depending on the region.

Technology

Ethanol is produced from the fermentation of sugar by enzymes produced from specific varieties of yeast. The five major sugars are the five-carbon xylose and arabinose and the six-carbon glucose, galactose, and mannose. Traditional fermentation processes rely on

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yeasts that convert six-carbon sugars to ethanol. Glucose, the preferred form of sugar for fermentation, is contained in both carbohydrates and cellulose. Because carbohydrates are easier than cellulose to convert to glucose, the majority of ethanol currently produced in the United States is made from corn, which produces large quantities of carbohydrates. Also, the organisms and enzymes for carbohydrate conversion and glucose fermentation on a commercial scale are readily available.

Two common methods for converting cellulose to sugar are dilute acid hydrolysis and concentrated acid hydrolysis, both of which use sulfuric acid. Dilute acid hydrolysis occurs in two stages to take advantage of the differences between hemicellulose and cellulose. The first stage is performed at low temperature to maximize the yield from the hemicellulose, and the second, higher temperature stage is optimized for hydrolysis of the cellulose portion of the feedstock. Concentrated acid hydrolysis uses a dilute acid pretreatment to separate the hemicellulose and cellulose. The biomass is then dried before the addition of the concentrated sulfuric acid. Water is added to dilute the acid and then heated to release the sugars, producing a gel that can be separated from residual solids. Column chromatographic is used to separate the acid from the sugars.

Both the dilute and concentrated acid processes have several drawbacks. Dilute acid hydrolysis of cellulose tends to yield a large amount of byproducts. Concentrated acid hydrolysis forms fewer byproducts, but for economic reasons the acid must be recycled. The separation and reconcentration of the sulfuric acid adds more complexity to the process. In addition, sulfuric acid is highly corrosive and difficult to handle. The concentrated and dilute sulfuric acid processes are performed at high temperatures (100 and 220°C) which can degrade the sugars, reducing the carbon source and ultimately lowering the ethanol yield. Thus, the concentrated acid process has a smaller potential for cost reductions from process improvements. The National Renewable Energy Laboratory (NREL) estimates that the cumulative impact of improvements in acid recovery and sugar yield for the concentrated acid process could provide savings of 14 cents per

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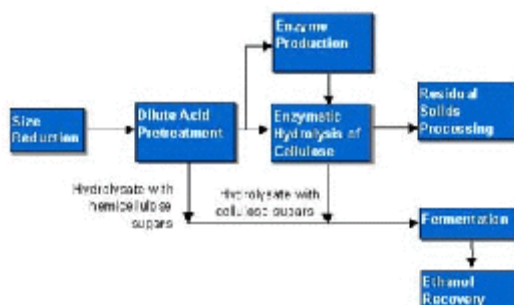
gallon, whereas process improvements for the dilute acid technology could save around 19 cents per gallon.

A new approach under consideration is countercurrent hydrolysis. Countercurrent hydrolysis is a two stage process. In the first stage, cellulose feedstock is introduced to a horizontal co-current reactor with a conveyor. Steam is added to raise the temperature to 180°C (no acid is added at this point). After a residence time of about 8 minutes, during which some 60 percent of the hemicellulose is hydrolyzed, the feed exits the reactor. It then enters the second stage through a vertical reactor operated at 225°C. Very dilute sulfuric acid is added to the feed at this stage, where virtually all of the remaining hemicellulose and, depending on the residence time, anywhere from 60 percent to all of the cellulose is hydrolyzed. The countercurrent hydrolysis process offers more potential for cost reductions than the dilute sulfuric acid process. NREL estimates this process may allow an increase in glucose yields to 84 percent, an increase in fermentation temperature to 55°C, and an increase in fermentation yield of ethanol to 95 percent, with potential cumulative production cost savings of about 33 cents per gallon.

The greatest potential for ethanol production from biomass, however, lies in enzymatic hydrolysis of cellulose.⁷ The enzyme cellulase, now used in detergents and in the textile industry to stone wash denim, simply replaces the sulfuric acid in the hydrolysis step. The cellulase can be used at lower temperatures, 30 to 50°C, which reduces the degradation of the sugars. In addition, process improvements now allow simultaneous saccharification and fermentation (SSF). In the SSF process, cellulase and fermenting yeast are combined, so that as sugars are produced, the fermentative organisms convert them to ethanol in the same step.

⁷ Other technologies for producing ethanol from biomass will be examined later in the report. It is premature to make the judgement whether enzymatic hydrolysis is the "most promising" technology.

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In the long term, enzyme technology is expected to have the biggest payoff. NREL estimates that future cost reductions could be four times greater for the enzyme process than for the concentrated acid process and three times greater than for the dilute acid process. Achieving such cost reductions would require substantial reductions in the current cost of producing cellulase enzymes and increased yield in the conversion of nonglucose sugars to ethanol. Once the hydrolysis of the cellulose is achieved, the resulting sugars must be fermented to produce ethanol. In addition to glucose, hydrolysis produces other six-carbon sugars from cellulose and five-carbon sugars from hemicellulose that are not readily fermented to ethanol by naturally occurring organisms. They can be converted to ethanol by genetically engineered yeasts that are currently available, but the ethanol yields are not sufficient to make the process economically attractive. It also remains to be seen whether the yeasts can be made hardy enough for production of ethanol on a commercial scale.

Conclusion

Ethanol has enjoyed some success as a renewable fuel, primarily as a gasoline volume extender and also as an oxygenate for high-oxygen fuels, an oxygenate in RFG in some markets, and potentially as a fuel in flexible-fuel vehicles. A large part of its success has been the Federal ethanol subsidy. With the subsidy due to expire in 2007, however, it is not clear whether ethanol will continue to receive political support. Thus, the future of ethanol may depend on whether it can compete with crude oil on

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its own merits.

Significant barriers to the success of cellulose-derived ethanol remain. For example, it may be difficult to create strains of genetically engineered yeast that are hardy enough to be used for ethanol production on a commercial scale. In addition, genetically modified organisms may have to be strictly contained. Other issues include the cost and mechanical difficulties associated with processing large amounts of wet solids. Proponents of biomass ethanol remain confident, however, that the process will succeed and low-cost ethanol will become a reality.⁸

Again, we look forward to following the progress of the Energy Policy Act of 2002 and the State Energy Conservation Office report.

⁸ Joseph DiPardo "Outlook for Biomass Ethanol Production and Demand" United States Department of Energy, Energy Information Agency. April 2000

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ANAEROBIC DIGESTERS

Generation of power from anaerobic digestion of animal manures began at the farm level in the United States in the early 1970s. Increasing awareness that anaerobic digesters can help control animal waste odor and aid in disposal has stimulated renewed interest in the technology. Farmers, dairymen, and feedlot operators faced with increasing federal and state regulation of the waste their animals produce are looking for ways to comply. New digesters now are being built because they allow their operators to manage the potential air and water quality issues associated with animal manures.

Anaerobic digesters (AD) isolate a naturally occurring process, the decomposition of organic materials, in an oxygen-free and high-temperature

Anaerobic digesters (AD) isolate a naturally occurring process, the decomposition of organic materials, in an oxygen-free and high-temperature environment. Under these conditions, the bacterium “digests” the material into simple organic matter and biogas.⁹ (This process differs from composting in that aerobic decomposition requires a large amount of oxygen and produces heat.) The digested material can be used as a soil treatment as it is rich in nutrients (ammonia, phosphorus, potassium, and more than a dozen trace elements) and the biogas can be used as a fuel or flared.¹⁰ Depending on the feedstock and the management of the process, biogas is comprised of between 50-80% methane, 20-40% carbon dioxide, and trace levels of hydrogen, carbon monoxide, nitrogen, oxygen, and hydrogen sulfide.

The U.S. Department of Energy’s Energy Efficiency and Renewable Energy Network,

⁹ Anaerobic bacteria evolved before photosynthesis of green plants released great quantities of oxygen into the atmosphere. As such, it is one of the oldest forms of life on earth. It naturally occurs in swamps, water-saturated soils and rice fields, deep bodies of water, and in the digestive systems of termites and large animals.

¹⁰ Henry, Chris and Koelsch, Rich. What is an Anaerobic Digester? Manure Matters. Vol. 7 No. 10. 2001. Lincoln, Nebraska: University of Nebraska. p. 1

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describes the fundamentals of the digestion process and digester design:

The Digestion Process

Anaerobic decomposition is a complex process. It occurs in three basic stages as the result of the activity of a variety of microorganisms. Initially, a group of microorganisms converts organic material to a form that a second group of organisms utilizes to form organic acids. Methane-producing (methanogenic) anaerobic bacteria utilize these acids and complete the decomposition process.

A variety of factors affect the rate of digestion and biogas production. The most important is temperature. Anaerobic bacteria communities can endure temperatures ranging from below freezing to above 135° Fahrenheit (F) (57.2° Centigrade [C]), but they thrive best at temperatures of about 98°F (36.7°C) (mesophilic) and 130° F (54.4°C) (thermophilic). Bacteria activity, and thus biogas production, falls off significantly between about 103° and 125°F (39.4° and 51.7°C) and gradually from 95° to 32°F (35° to 0° C).

In the thermophilic range, decomposition and biogas production occur more rapidly than in the mesophilic range. However, the process is highly sensitive to disturbances such as changes in feed materials or temperature. While all anaerobic digesters reduce the viability of weed seeds and disease-producing (pathogenic) organisms, the higher temperatures of thermophilic digestion result in more complete destruction. Although digesters operated in the mesophilic range must be larger (to accommodate a longer period of decomposition within the tank [residence time]), the process is less sensitive to upset or change in operating regimen.

To optimize the digestion process, the digester must be kept at a consistent temperature, as rapid changes will upset bacterial activity. In most areas of the United States, digestion vessels require some level of insulation and/or heating. Some installations circulate the coolant from their biogas-powered engines in or around the digester to keep it warm,

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while others burn part of the biogas to heat the digester. In a properly designed system, heating generally results in an increase in biogas production during colder periods. The trade-offs in maintaining optimum digester temperatures to maximize gas production while minimizing expenses are somewhat complex. Studies on digesters in the north-central areas of the country indicate that maximum net biogas production can occur in digesters maintained at temperatures as low as 72°F (22.2°C).

Other factors affect the rate and amount of biogas output. These include pH, water/solids ratio, carbon/nitrogen ratio, mixing of the digesting material, the particle size of the material being digested, and retention time. Pre-sizing and mixing of the feed material for a uniform consistency allows the bacteria to work more quickly. The pH is self-regulating in most cases. Bicarbonate of soda can be added to maintain a consistent pH, for example when too much "green" or material high in nitrogen content is added. It may be necessary to add water to the feed material if it is too dry, or if the nitrogen content is very high. A carbon/nitrogen ratio of 20/1 to 30/1 is best. Occasional mixing or agitation of the digesting material can aid the digestion process. Antibiotics in livestock feed have been known to kill the anaerobic bacteria in digesters. Complete digestion, and retention times, depend on all of the above factors.

Phil Lusk, in *Methane Recovery from Animal Manures: the Current Opportunities Casebook* describes the various types of digesters:

Plug Flow Digester

The basic plug-flow digester design is a long rectangular trough, often built below ground level, with an air-tight expandable cover. Manure is collected daily and added to one end of the trough. Each day a new "plug" of manure is added, slowly pushing the other manure down the trough. The size of the plug-flow system is determined by the size of the daily plug. As the manure progresses through the trough, it decomposes and produces methane that is trapped in the expandable cover. To

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protect the flexible cover and maintain optimal temperatures, some plug-flow digesters are enclosed in simple greenhouses or insulated with a fiberglass blanket. An often vital component of a plug-flow digester is the mixing pit, which allows the total solids concentration of the manure to be adjusted to a range of 11 to 13 percent by dilution with water. Many systems use a mixing pit with a capacity roughly equal to one day's manure output to store manure before adding it to the digester.

A plug-flow digester requires minimal maintenance. Inside the digester, suspended heating pipes allow hot water to circulate. The hot water heats the digester to keep the slurry at 25°C to 40°C (77°F to 104°F), a temperature range suitable for methane-producing bacteria. The hot water can come from recovered waste heat from an engine generator. This design type is best for dairy waste, as swine waste has a low fiber content.

Complete Mix Digesters

Complete-mix digesters can handle manures with total solids concentrations of three to ten percent, and generally can handle substantial manure volumes. The reactor is a large, vertical, poured concrete or steel circular container. The manure is collected in a mixing pit by either a gravity-flow or pump system. If needed, the total solids concentration can be diluted, and the manure can be preheated before it is introduced to the digester reactor. The manure is deliberately mixed within the digester reactor. The mixing process creates a homogeneous substrate that prevents the formation of a surface crust and keeps solids in suspension. Mixing and heating improve digester efficiency. Complete-mix digesters operate at either the mesophilic or thermophilic temperatures range.

A fixed cover is placed over the complete-mix digester to maintain anaerobic conditions and to trap the methane-rich biogas produced. The methane is removed from the digester, processed, and transported to the site of end-use application. The most common application for methane produced by the digestion process is electricity generation

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using a modified internal combustion engine. Both the digester and the mixing pit are heated with waste heat from the engine cooling system. Complete-mix digester volumes range considerably from about 3,500 to 70,000 cubic feet (ft³). This represents daily capacities of about 25,000-500,000 gallons of manure/digester. Larger volumes are usually handled by multiple digesters.

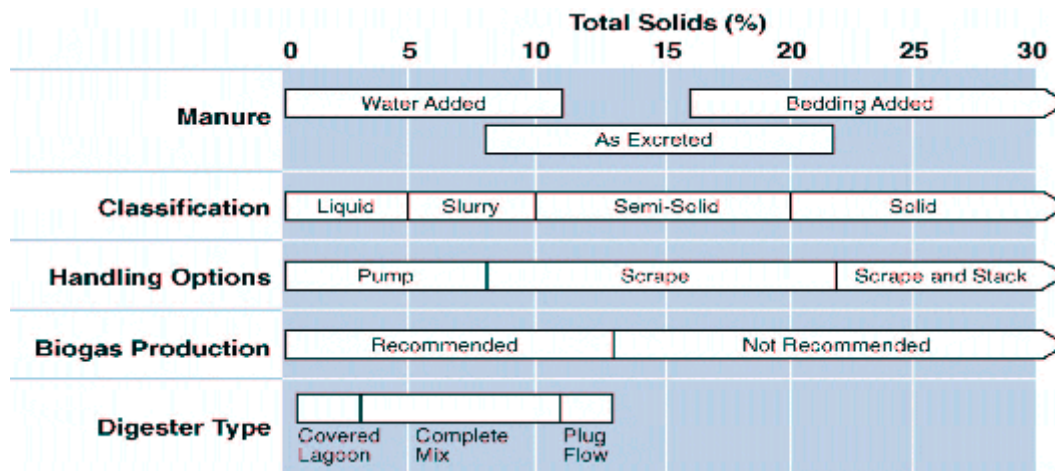
Covered Anaerobic Lagoons:

Many livestock operations store the manure they produce in waste lagoons. A growing number of these operations are placing floating covers with manifolds on their lagoons to capture the biogas. They work best with swine or dairy waste which use a hydraulic flushing system, typical in the southeastern and southwestern parts of the United States, to transport manure to the lagoon. Total solids concentration should be less than two percent. A properly designed and operated anaerobic lagoon system, in which the hydraulic retention time exceeds 60 days, may produce significant quantities of methane. Covered lagoon digester operation and maintenance is simple and straightforward compared to complete-mix and plug-flow digesters. The capital costs for this type of digester can be less than those required for the complete-mix and plug-flow types of conventional digesters.¹¹

¹¹ Lusk, Phil. (September 1998). Methane Recovery from Animal Manures: the Current Opportunities Casebook. NREL/SR-25145. NREL. Golden, CO.

The AgStar program, a cooperative effort of US EPA, USDA, and DOE provides free software to aid the decision on whether or not a digester is best for a given set of circumstances. It can be downloaded at <http://www.epa.gov/agstar/library/handbook.html>

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Managing Manure with Biogas Recovery Systems: Improved Performance at Competitive Cost <http://www.epa.gov/agstar/library/manage.pdf>

Economics

Anaerobic digester system costs vary widely. Some systems can be put together using off-the-shelf materials. Sophisticated systems have been designed by professionals whose major focus has either been large scale industrial projects or research, not low cost. Factors to consider when building a digester are cost, size, the local climate, the operator's capacity for performing maintenance, and the availability and type of organic feedstock material.

In the United States, the availability of inexpensive fossil fuels has limited the use of digesters solely for biogas production. However, the waste treatment and odor reduction benefits of controlled anaerobic digestion are receiving increasing interest, especially for large-scale livestock operations such as dairies, feedlots, and slaughterhouses. Where costs are high for sewage, agricultural, or animal waste disposal, and the effluent has economic value, anaerobic digestion and biogas production can reduce overall operating costs. Biogas production for generating cost effective electricity requires manure from more than 150 large animals.

Promising future waste-to-profit activities enhance the economic performance of the overall farm manure management system. New end-use applications that can provide added value to coproducts and maximize nutrient use include advanced electricity

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generation and process heat, greenhouses, and algae, plant, and fish aquaculture.

A major challenge facing digester projects is transmitting the energy generated to areas in the country where it is needed most. Jay Morrison, senior regulatory counsel for the National Rural Electric Cooperative Association, admitted that while co-ops are interested in distributed generation and renewable generation, getting energy onto the grid is difficult at best.

"Don't presume that just because you build generation, you can deliver it to market. It's almost impossible to build transmission (lines) these days," Morrison said. "We're trying to find ways to lower the cost for inter-connection. However, try to find out as much information as you can before you invest. If you talk to the utility first, you can save a lot of time and money."

Digester Projects in Texas

There is one operational anaerobic digester project in the Texas Panhandle and two are currently being contemplated in Central Texas.

Premium Standard Farms, Inc. at Dalhart, Texas has constructed two covered, heated, mesophilic, anaerobic digesters to treat the effluent produced by two newly constructed production facilities. The digesters were chosen over traditional lagoons because of their ability to reduce odors and the overall size of treatment system is 85% smaller than traditional facultative lagoons. The mesophilic digester has an optimal operating temperature of 85 to 95 degrees Fahrenheit, which requires supplemental heat be added to the system. Approximately 80% of the methane generated by the digester will be used to fuel the boiler that generates steam to heat the digester. The remaining methane is available to generate electricity, which will be evaluated when the systems are up and running and we can quantify the amount of excess gas produced.

Both digesters are covered with an 80 millimeter plastic cover. A network of PVC pipes under the cover collect the biogas and a blower located adjacent to the boiler pulls gas from the digester and sends it to the boiler. Any excess gas is flared.

One digester is located on a 10,000 sow site. The 2 million gallon continuous flow

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digester receives 75,000 gallons of effluent per day. They project the system will produce 125 mcf of biogas per day and 65% of the biogas will be methane.

The other digester is located on a 108,000 pig finishing site. This digester has a capacity of 18 million gallons and receives a flow of 725,000 gallons of effluent. They project it to produce 938 mcf of biogas of which 630 mcf is methane.¹²

The City of Waco and the Brazos River Authority are talking about the feasibility of a regional centralized digester system and the Texas Farm Bureau looking into setting up a smaller-scale operation at a dairy. As these projects progress, we look forward to receiving the benefit of their experience.¹³

¹² Phone interview. Tom McDonald. June 12, 2002.

¹³ Phone interview. John Hofman. June 11, 2002. Phone interview. Ned Meister. June 10, 2002.

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CREATING ENERGY THROUGH BIOMASS

As mentioned previously in this report, biomass is any kind of vegetation: trees, grasses, plants parts such as leaves, stems and twigs, and ocean plants, however, wood is currently the most commonly used biomass fuel for heat and power. Industries such as agriculture, forest products, transportation, and construction can supply large quantities of wastes from wood and plant products.

Again, fast-growing energy crops may be cultivated as a biomass fuel. These energy crops will be genetically tailored plants designed to be fast-growing, drought resistant, and readily harvested, allowing them to become a competitively-priced fuel. The U.S. Department of Energy is working with national labs, agricultural and forestry groups, power companies, and other governmental agencies to make energy crops a viable fuel source in the near future. While not excluding them from our consideration, our interest is primarily in agricultural wastes.

Technologies

We will rely on the U.S. Department of Energy to explain the different types of biomass processing technology. These technologies differ from the ones discussed in the first section of this report, the energy produced using a biomass feedstock is not ethanol.

Combustion

Biomass can be burned to produce steam, the steam turns a turbine and the turbine drives a generator, producing electricity. Because of potential ash build-up (which fouls boilers, reduces efficiency and increases costs), only certain types of biomass materials are used for direct combustion.

Cofiring

For utilities and power generating companies with coal-fired capacity, cofiring with biomass may represent one of the cheapest renewable

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energy options. Cofiring involves replacing a portion of the coal with biomass at an existing power plant boiler. This can be done by either mixing biomass with coal before fuel is introduced into the boiler, or by using separate fuel feeds for coal and biomass. Depending on the boiler design and fuel feed system employed, biomass can replace up to 15% of coal in a cofiring operation.

Boiler technologies where cofiring has been practiced, tested, or evaluated, include wall fired and tangentially designed pulverized coal (PC) boilers, coal-fired cyclone boilers, fluidized-bed boilers, and spreader stokers. The current coal-fired power generating system represents a direct system for carbon mitigation by substituting biomass-based renewable carbon for fossil carbon. Extensive research and development field validation tests and trials have shown that biomass energy can be substituted for up to 15% of the total energy input by modifying little more than the burner and feed intake systems.

Preparing biomass for cofiring involves well known technologies. After "tuning" the boiler's combustion output, there is little or no loss in total efficiency, implying that the biomass combustion efficiency to electricity would be close to the 33-37% range. Since biomass in general has significantly less sulfur than coal, there is an SO₂ benefit, and early test results suggest that there is also a NO_x reduction potential of up to 30% with woody biomass. Investment levels are very site specific and are affected by the available space for yarding and storing biomass, installing size reduction and drying facilities, and the type of boiler burner modifications.

Gasification

Gasification is a major and unique element in the development of improved BioPower systems. It is a thermochemical process that converts solid biomass raw materials to a clean fuel gas form. The fuel gas form allows biomass to use a wide range of energy conversion devices to produce power: gas turbines, fuel cells, reciprocating - engines. This process gives biomass tremendous flexibility in the way it

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can be used to produce power.

Gasification is a two-step, heat absorbing process in which a solid fuel (biomass or coal) is thermochemically converted into a low- or medium-Btu gas. In the first reaction, pyrolysis, the volatile components of the fuel are vaporized at temperatures below 600C (1100F) by a set of complex reactions.¹⁴

Included in the volatile vapors are hydrocarbon gases, hydrogen, carbon monoxide, carbon dioxide, tar, and water vapor. Because biomass fuels tend to have more volatile components (70-86% on a dry basis) than coal (30%), pyrolysis plays a larger role in biomass gasification than in coal gasification. Char (fixed carbon) and ash are the pyrolysis by-products which are not vaporized. In the second step, the char is gasified through reactions with oxygen, steam, and hydrogen. Some of the unburned char is combusted to release the heat needed for the endothermic gasification reactions.

Gasification is an additional process step that not only produces a more easily used fuel form for power generation equipment, but provides the means to remove fuel components that are problems for downstream power generation systems. A wide variety of biomass materials can be gasified, many of which would be difficult or impossible to burn otherwise. Gasification offers one means of processing waste fuels, many of which can be problematic.

¹⁴ **Pyrolysis:** The thermal decomposition of biomass at high temperatures (greater than 400° F, or 200° C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

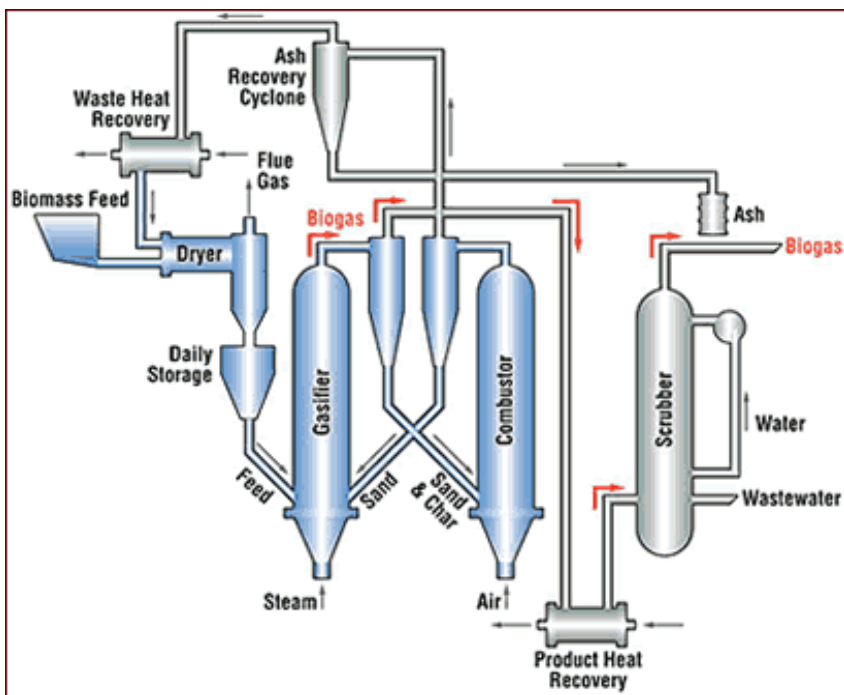
Department of Energy, Biopower glossary. <http://www.eren.doe.gov/biopower/basics/ba_glossary.htm#P>

Heat is used to chemically convert biomass into a pyrolysis oil. The oil, which is easier to store and transport than solid biomass material, is then burned like petroleum to generate electricity. Pyrolysis also can convert biomass into phenol oil, a chemical used to make wood adhesives, molded plastics and foam insulation.

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Low-Pressure Gasification

The Vermont Gasifier operates at low pressure, has a high throughput, and produces a medium-Btu gas that can directly fuel a standard, unmodified gas turbine. DOE is currently co-sponsoring a scale-up demonstration of a low-pressure gasifier in Burlington, Vermont.



The gasifier at McNeill Station in Burlington, VT operates at low pressure, has a high throughput, and produces a medium-Btu gas that can directly fuel a standard, unmodified gas turbine

his process uses two

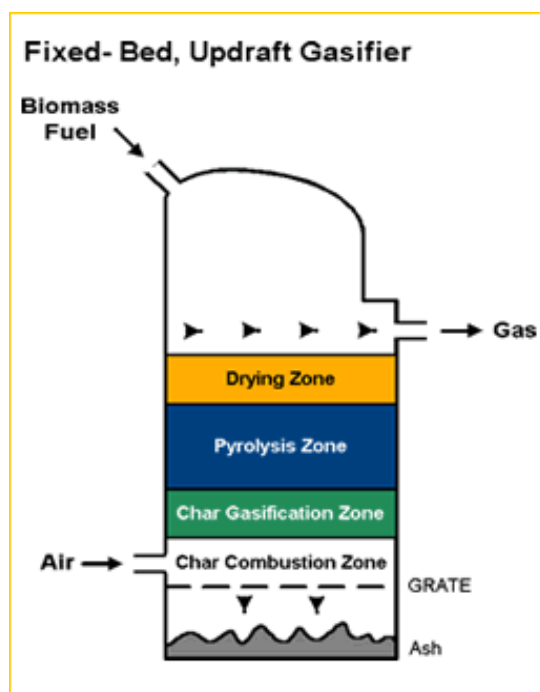
reactors where two separate chemical reactions take place. In the first reactor, biomass is surrounded by hot sand where pyrolysis takes place and the volatile chemical components of biomass separate from the remaining solids consisting of char, ash, and the sand. The gases are separated from the solids in a cyclone separator, and the sand and char

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move onto the second reactor. There the char is burned to provide heat for the pyrolysis and gasification in the first reactor.

The gas passes through a scrubber to remove particulate matter to meet the particulate specifications of a gas turbine. The resulting gas has a medium-Btu content of about 500 Btu per cubic feet and is suitable for fueling a standard gas turbine. The most successful of the fixed-bed designs is the updraft gasifier, in which the biomass is fed from the top of the gasifier and successively undergoes drying, pyrolysis, char gasification, and char combustion as it settles to the bottom of the gasifier. The product gas is removed from the top of the gasifier and the ash from the bottom.

Blast air and steam are injected into the gasifier to keep the ash below melting temperatures (in a dry-ash gasifier) and to facilitate char conversion. The product gas from this process has a low velocity and low temperature. The low operating temperature creates a considerable amount of condensable oils and tars in the product gas. However, the filtering effect of the bed and low stream velocities create a product gas with low particulate concentrations.



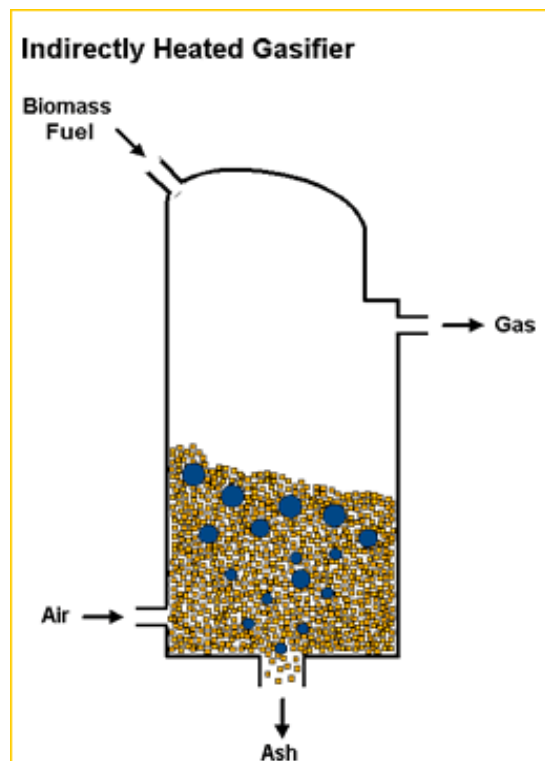
Because of the volatility of biomass, the excellent heat transfer design, and high peak temperatures found in the fixed-bed design, carbon conversion efficiency is typically 99%; the hot gas efficiency is in the range of 90-95%. Furthermore, the design and operation of the fixed-bed is relatively simple and is the most widely used commercially. The fixed-bed gasifier, however, requires large, dense, uniformly sized fuels. Thus, agricultural residues would generally require densification,

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thereby increasing fuel handling costs.

In a fluidized-bed gasifier, a continuous feed of biomass and inert heat-distributing material (i.e. sand) is "fluidized" by an oxidant and/or steam. There are two options for the way in which heat is supplied to the gasifier. In a directly heated fluidized bed gasifier, heat required for gasification comes from char combustion in the gasified reactor.

In an indirectly heated fluidized bed gasifier, char is removed from the gasified and burned in a separate vessel. The resulting heat is transferred to the gasified by either in-bed heat exchangers or by recirculating the inert bed material heated in the char combustor. The advantage of indirect heating is that gasification product is not diluted with the char combustion by-products.



In either design, pyrolysis takes place throughout the bed and is not localized. Because the injected air prevents the ash from melting, steam injection is not always required. As in the fixed-bed design, the product gas is drawn from the top of the gasified. The superior mixing which occurs in the fluidized-bed generates excellent heat and mass transfer which subsequently yield uniform temperatures, better fuel-moisture utilization (fuel moisture to keep bed temperatures below the ash melting temperatures), and faster reactions. These benefits allow higher throughput capabilities which, in turn, can reduce the size and capital cost of the gasified. Also, although the peak temperatures are lower, the average temperature in a fluidized-bed is greater than in a fixed-bed. A significant amount of tars and oils are converted into permanent gases.

Product gas composition, carbon efficiency, and hot gas efficiency for the fluidized-bed process are comparable to those found in the fixed-bed designs. Fluidized-bed designs, however, are capable of handling much smaller, less dense, and less uniform feedstocks. In fact, the fuel and fuel handling systems are more likely to set

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the lower limits for the acceptable bulk density. A shortcoming of the fluidized-bed design is the high particulate level in the raw gas.¹⁵

Economics of BioPower

The cost to generate electricity from biomass varies depending on the type of technology used, the size of the power plant, and the cost of the biomass fuel supply. Biomass power systems range in size from a few kW (enough for an average U.S. home) for on-site generation units, up to 80 MW for power plants. Each MW of biopower capacity generates enough electricity in a year to power about 525 average U.S. homes. Limitations on locally available biomass resources generally make it disadvantageous to exceed 100 MW in size. Once advanced biomass power systems (gasification combined-cycles) become commercially available, larger generation units will be more feasible.

Today, cofiring offers power plant managers a relatively low cost and low risk route to add biomass capacity. These projects require small capital investments per unit of power generation capacity. Cofiring systems range in size from 1 to 30 MW of biopower capacity. When low cost biomass fuels are used, cofiring systems can result in payback periods as low as 2 years.

A typical existing coal fueled power plant produces power for about 2.3 ¢/kWh. Cofiring inexpensive biomass fuels can reduce this cost to 2.1 ¢/kWh. In today's direct-fired biomass power plants, generation costs are about 9 ¢/kWh. In the future, advanced technologies such as gasification-based systems could generate power for as little as 5 ¢/kWh. For comparison, a new combined-cycle power plant using natural gas can generate electricity for about 4 to 5 ¢/kWh at today's gas prices.

For biomass to be economical as a power plant fuel, transportation distances from the resource supply to the power generation point must be minimized, with the maximum economically feasible distance being less than 100 miles. The most economical conditions exist when the energy use is located at the site where biomass residue is generated (i.e., at a paper mill, sawmill, or sugar mill). Modular Biopower

¹⁵ "Biopower: Technologies." U.S. Department of Energy.
<<http://www.eren.doe.gov/biopower/technologies/index.htm>>

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generation technologies under development by the U.S. Department of Energy and industry partners will minimize fuel transportation distances by locating small-scale power plants at biomass supply sites.

Biomass projects in Texas

Texas A&M University is working on a project investigating cattle feedlot and chicken litter biomass co-firing with coal to find optimum operating parameters and maximum combustion efficiency with least emissions. Experiments were performed in a small scale boiler burner facility with coal only and then for 80:20 blends on a wet-weight (as-received) basis. Three types of feedlot manure were examined for blending: raw feedlot manure (RM), partially composted feedlot manure (PC), and finished composted (FC) feedlot manure. Currently more small-scale and pilot-plant experiments are in progress.

A project recently conducted at Texas A&M-Kingsville under the direction of Dr. Peter Felker focused on developing a harvester suitable for high density stands of small-diameter woody trees or shrubs such as mesquite. The major constraint to utilization of small, shrubby biomass on most of the land area of the arid western US is the lack of economically viable harvesting systems. Farm equipment is not engineered to withstand the loads of shrubby woody biomass. Traditional forestry equipment, designed to harvest large individual trees, takes too much time per shrub to be economically viable with thousands of small shrubs per acre.¹⁶

From a national perspective, the quantities of harvestable biomass are significant. For example, mesquite exists on 75 million acres in the US with 55 million acres in Texas. The amount of biomass in mesquite ranges from 1.2 to 16 tons per acre. Thus the total biomass resource for mesquite in the southwest US would range from 90 million to 1,200 million tons. In south Texas, dense regrowth containing 2 to 4 dry tons per acre can occur in 15 years.

¹⁶ Badger, Phillip C. "A Biomass Harvester for Small Diameter Trees and Shrubs." Evergreen Vol. 4 No. 3. August/September 1999. New Uses Council.
<<http://www.newuses.org/EG/EG-19/19harvester.html>>
The project was shelved due to lack of funding.

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Conclusion

Without question, Texas has an abundance of feedstock materials for biomass fuel production. As harvesting, collection, and processing technologies become more cost effective, biomass will present an enormous opportunity for waste-to-energy projects.

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RECOVERING ENERGY FROM SOLID WASTES

Landfills offer yet another opportunity to make use waste for energy. A recent method of deriving energy from waste is the collection and combustion of landfill gas. Landfill gas is produced by the natural anaerobic decomposition of organic matter in landfills. Composed of 40-60% methane (CH_4), with the remainder being largely carbon dioxide. Landfill gas has a gross heating value of about 17,000 kilojoules per cubic meter, about half that of traditional natural gas. Each ton of MSW produces about 70 cubic meters of landfill gas.

Methods of collecting landfill gas depend upon the design of a particular landfill. Methane is a potentially explosive gas, so many landfills designed in the past twenty years have been built with a system of pipes which is used to collect methane. This gas has traditionally been simply flared, but is now in many cases collected as a useful fuel. Landfills not built with methane collection systems can have small diameter wells drilled and perforated plastic pipes installed to provide a collection and recovery system. Pumps are required to remove the gas, and necessitate increased maintenance costs. Slightly larger landfills can use gas turbines, similar to jet engines to generate electricity and heat. Gas turbines are more efficient than reciprocating engines and are generally more tolerant of impurities in the gas. Finally, large volumes of gas can be used to power a traditional thermal steam generating station. This set up can handle most impurities and can also mix landfill gas with natural gas to increase generating capacity when needed.

Landfill methane projects can involve a variety of power generation technologies in a wide range of sizes. The size and type of generation technology depends upon the amount of methane captured. Landfills with low capture rates can use internal combustion engines (250 kW and up), ones with medium capture rates can use gas turbines (3 MW and up), ones with high capture rates can use Rankine Cycle steam turbines (8 MW and up), and ones with very high capture rates can utilize combined cycle engines (20 MW and up).

Landfill methane project economics are promising—electricity costs for different landfill methane options all fall within the range of costs for new combined cycle

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natural gas plants.¹⁷

Environmental Considerations

Capturing the environmental and economic benefits associated with LFG resources requires conversion technologies that neutralize environmental damage associated with landfill sites, and at the same time produce salable energy at marketable prices. Increased LFG recovery depends on low cost conversion technologies capable of producing electricity at prices that electric utilities are willing or required by regulation to pay.

Conversion Technologies

We rely on SCS Engineers' "Comparative Analysis of Landfill Gas Utilization Technologies" to outline technologies. Landfill gas is converted into electricity and/or heat by one of three distinct technologies.

Internal Combustion Systems

Internal combustion systems include reciprocating engines that operate on a thermodynamic "Otto Cycle," and gas turbines that operate on a thermodynamic "Brayton Cycle." Conceptually, internal combustion systems ignite and combust a fuel/air mixture within the engine or turbine. The combustion causes a pressure force which can be directly translated into usable energy.

The most common types of internal combustion technologies used to produce electricity from LFG are reciprocating engines and gas turbines. Advantages of ICRE include higher efficiency, use of low pressure fuel gas compressor, adaptability to variable LFG supplies, suitability for moderate size landfills, and lower capital cost. Some disadvantages of ICRE include: higher emissions, more complex cooling systems, more moving parts, higher maintenance cost. Advantages of

¹⁷ Singh, Virinder. "Biomass: Landfill Methane, Explained." Renewable Energy Policy Project.
<http://www.crest.org/articles/static/1/988047061_7.html>

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gas turbines include: low emissions, no cooling water required, simple lubricating system, few moving parts and wear points, a vibration-free operation, and exhaust which can be utilized in cogeneration. Some disadvantages of gas turbines are: lower efficiency, high pressure fuel gas compressor required, high capital cost, unsuitable for moderate size landfills, sensitivity to varied LFG supply loads, sensitivity to ambient air temperature.

External Combustion Systems

External combustion systems use an external combustion source as a heat supply for the energy conversion system. These include the "Organic Rankine Cycle," and the "Stirling Cycle," each of which uses a working fluid or gas which is heated and cooled using external heat. The changes in temperature cause changes in volume and pressure which can be translated into usable energy.

The ORC system has two primary advantages over other LFG conversion technologies such as gas turbines and reciprocating engines. These advantages are the ability to convert the heat energy from the combustor to mechanical power, allowing for a very high capacity factor, and low pollutant emissions without secondary equipment. Advantages of ORC include: high capacity factor, emissions limited to fugitive losses, not sensitive to varied fuel supply loads, simple auxiliary systems, limited moving components, vibration-free low-noise operation, ability to be added to existing flare system, and automated operation. Some disadvantages include: high heat rate, high capital cost, and sensitivity to ambient air temperature variations.

At present, the primary disadvantage for a Stirling Cycle engine is its early stage of development. As with any new technology, development costs can be very expensive, and it can take time and experience to prove a technology for open acceptance in the market. Advantages include: working gas sealed inside a vessel, low emissions, low noise, and internal parts are not in contact with contaminants from LFG fuel. However, the technology is not proven, it is not commercially available,

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and has a high capital cost.

Electrochemical Systems

Fuel cells use a variety of chemical reactions to create an electron transfer and thus a direct current. These are not combustion processes. Two types of fuel cells that appear to be promising for LFG conversion are the Phosphoric Acid Fuel Cell (PAFC) and the Molten Carbonate Fuel Cell (MCFC).

Currently, the phosphoric acid fuel cell appears to be further along in development and operation; however, the molten carbonate fuel cell is gaining interest because of its higher operating temperature. The increase in heat simplifies the reforming section by allowing the reformation process to occur within the fuel cell, which further reduces pollutant emissions. The temperature also generates a higher grade heat for cogeneration. Advantages of fuel cells are: high efficiency, low emissions, low noise, suitability for urban areas, modular construction, low water requirement, high grade waste heat for cogeneration, remote operation, few moving parts. Disadvantages include: high capital cost, newness of the technology, and complex LFG pretreatment system.¹⁸

EPA's Landfill Methane Outreach Program

U.S. EPA's Landfill Methane Outreach Program (LMOP) is a voluntary assistance and partnership program that facilitates and promotes the use of landfill gas as a renewable energy source. By preventing emissions of methane through the development of landfill gas energy projects, LMOP helps businesses, states, and communities protect the environment and build a sustainable future.

Waste to Energy Programs in Texas

¹⁸ SCS Engineers. "Comparative Analysis of Landfill Gas Utilization Technologies." Northeast Regional Biomass Program Policy Research Center, Inc. <<http://www.nrbp.org/pdfs/abstr07.pdf>>

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Appendix B is a list of landfill waste-to-energy facilities in Texas. The Texas Public Utility Commission is presently working on a survey of those facilities and will produce an updated list and report in the fall.

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GRAVITY PRESSURE VESSEL

In our Amarillo hearing, the committee was introduced to a technology that does not easily fit into any of the above categories, yet could potentially be a technology that encompasses all of them. James Titmas of GeneSyst International, Inc. spoke about the gravity pressure vessel, which can process any kind of waste.

The principles of the technology are that water at very high pressure is contained in an underground in the form of liquid steam. With water at this supercritical state it dissolve oil, coal, and most any organic chemical. Once dissolved in this water, organics are quickly manipulated by injecting oxygen, acid, or a catalyst to achieve the desired end product.

Examples of these include the destruction of the concentrated biomass from a waste water treatment plant, the elimination of "off specification" chemical plant production, the elimination of wastes produced from cleaning process raw materials, the reduction in volume of low level radioactive wastes, the conversion of trash to fuel grade alcohol, the devulcanization of rubber, and so on. All of these have in common the factor that these processes are made practical by efficient means to do the process.

A gravity pressure vessel is a pipe that hangs vertically inside a steel lined chamber drilled and cemented into the earth. Wastes and water enter at the top of the pipe, are directed downward to the bottom of the pipe and then back up and out. Even though the water is always moving, the pressure at the bottom can be anywhere from 350 pounds per square inch to 3,500 pounds per square inch, depending on the depth of the vessel. The water coming up is warmer than the water going down. The cooler water going down is heavier the warmer water coming up. The heavier water pushes the lighter water up and out.

Advantages and Disadvantages of the Gravity Pressure Vessel

For countries that must import liquid fuels, or those which have oil reserves but do elect, out of necessity, to export oil, the impact of making automobile and truck fuels from existing and renewable internal resources available in the country is highly significant. The balance of trade is more favorable because foreign exchange is

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saved or optimized, money paid for this fuel stays in and re-circulates in the country in the form of wages paid for labor and support services. It is estimated that if existing landfill inventories and newly generated solid wastes are converted to ethanol, as much as 25% of oil and gasoline resources could be saved and used for industry or power generation.

The combustion of fossil fuels increases carbon dioxide in the atmosphere, which percentage may grow faster than the biosphere's ability to absorb that gas. The use of renewable organic material produces no net gain in carbon dioxide as the sources are not fossil fuels. Certain cities bordered by mountains on their leeward side, such as Los Angeles, Milan, and Mexico City must live with their exhaust products. Any fuel that will reduce the residuals of the partial combustion of fossil fuels and oils will result in cleaner air and reduced health risks.

The process of converting garbage and trash to ethanol and other byproducts converts a cost to an income. Because the gravity vessel process has no air emissions it can operate within the city itself. Collection distances would be short.

Local entrepreneurs working with small vehicles can also participate. This will maximize the number of persons employed and provide an incentive to rid the streets of wastes that may have been discarded in an uncontrolled manner, even those wastes that have already accumulated in the neighborhoods. Wastes can be delivered to our transfer facility without regard to the source of the waste. This program also makes no additional demands on the infrastructure of roads within the city. A GPV facility operates 24 hours per day allowing waste collection to be accomplished at night when traffic is at a minimum. That makes collection faster, safer, and more efficient.

Once the waste is collected at the transfer stations, persons will be employed to deliver wastes to a central facility. Once there and using local labor, the wastes will be converted to products including ethanol, furfural (an industrial solvent), yeast (a protein supplement for animal feed), liquid carbon dioxide (used in the oil industry and for flash freezing foods), urea (used as fertilizer), lime (used for road foundations and agriculture), acetic acid (used in industry), and other products.

The GPV process is not hampered by the wetness of the wastes that typically happens during the rainy seasons when wastes can become too wet to incinerate.

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The GPV process can be built very close to or even in the city because it has no emissions or odors, with obvious economic advantages for collection frequency and efficiency.

The Disadvantages

The GPV process requires just as much training and expertise as is needed for the landfill of garbage and trash, but less training than the operation of an incinerator. It requires a similar knowledge of the workings of mechanical equipment, its maintenance, and the required safety procedures.

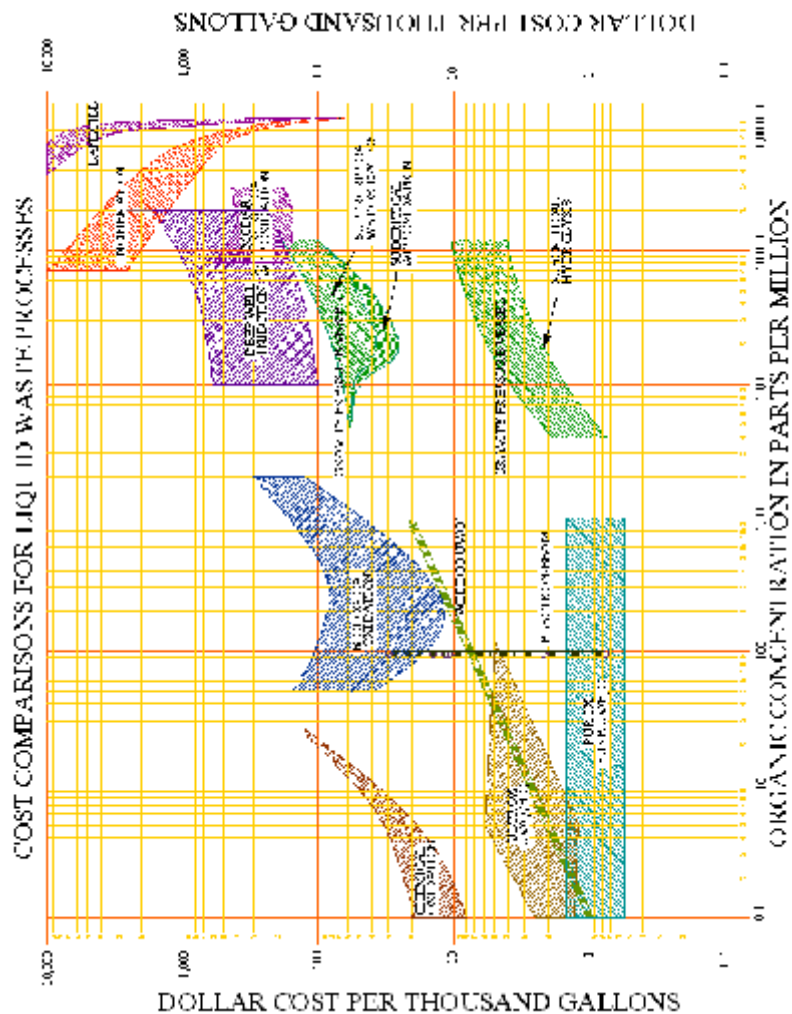
The GPV facility can be relocated, but it is not portable. For that reason it is necessary to carefully select where the operations will be needed for the next ten to twenty years. After that time it can be economically moved if necessary. The ability to relocate the facility at all is an advantage over a landfill operation, which will be in the same place forever.

Even though the GPV system can manage a very broad spectrum of very wet or dry wastes, it must be custom designed for each specific family of wastes. For that reason wastes must be sampled and tested prior to the final design of a commercial unit. An investment in a pilot operation is appropriate, an actually a necessity.¹⁹

The diagrams on the following pages will show the process by which the gravity pressure vessel produces the glucose solution which can be fermented into ethanol and a graphic representation of the dollar cost per thousand gallons of various forms of waste disposal.

¹⁹ Titmas, James A. "GPV Advantages and Disadvantages." Genesyst International. 2000.
<http://www.genesyst.com/Intro_to_GPV/Advantages_and%20Disad.htm>

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RESULTS OF THE COMMITTEE HEARINGS

This interim charge, while available for public comment at each Committee hearing, was a focus for the Committee at the following meetings:

Austin, Texas	December 3, 2001
Amarillo, Texas	April 23, 2002

The submitted written testimony is incorporated into this report. Oral testimony is available on the Senate's archived audio of the committee's hearings at www.senate.state.tx.us.

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CONCLUSIONS/RECOMMENDATIONS

In his charge, the Lieutenant Governor showed vision in directing the Committee to examine the research and use of alternative fuels. In its review of this matter, the Committee heard testimony from state agencies, interest groups, and the public at large. In the course of the testimony and other findings of the Committee, it is recognized that alternative fuels and fuel additives made from agricultural and solid wastes can help Texas solve air and water quality problems and be a source of economic development.

Based on its findings, the Committee has the following recommendations:

1. Encourage Texas Department of Agriculture, the Public Utility Commission, the State Energy Conservation Office and the Office of Rural Development to identify available funds from the 2002 Federal Farm Bill and assist applicants in obtaining funding for their alternative fuels projects.
2. Monitor the State Energy Conservation Office's ethanol industry feasibility study.
3. Examine the potential of biomass ethanol as a feedstock for fuel cells.
4. Encourage the development of alternative fuels as a tool for rural development.
5. Survey existing landfills and connect potential landfill gas recovery projects with U.S. Environmental Protection Agency's Landfill Methane Recovery Program.
6. Consider how an alternative fuels research infrastructure might be created in Texas.
7. Examine the potential benefits of coordinating methane-powered electric infrastructure with established composting projects.

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ACRONYMS AND ABBREVIATIONS

AD	anaerobic digester
DOE	Department of Energy
FC	finished composted feedlot manure
GPV	gravity pressure vessel
ICRE	internal combustion reciprocating engines
LFG	landfill gas
LMOP	Landfill Methane Outreach Program
MTBE	methyl tertiary-butyl ether
MSW	municipal solid waste
NREL	National Renewable Energy Laboratory
ORC	Organic Rankine Cycle
PC	partially composted feedlot manure
RFG	reformulated gasoline
RM	raw feedlot manure

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APPENDIX A:

Prepared by the U.S. Department of Energy
www.afdc.doe.gov/pdfs/fueltable.pdf

Properties of Fuels

Property	Gasoline	No. 2 Diesel Fuel	Methanol	Ethanol	MTBE	Propane	Compressed Natural Gas (CNG)	Hydrogen
Chemical Formula	C ₄ to C ₁₂	C ₃ to C ₂₅	CH ₃ OH	C ₂ H ₅ OH	(CH ₃) ₃ COCH ₃	C ₃ H ₈	CH ₄	H ₂
Molecular Weight	100–105 ^(a)	≈200	32.04	46.07	88.15	44.1	16.04	2.02 ^(x)
Composition, Weight %								
Carbon	85–88 ^(b)	84–87	37.5	52.2	66.1	82	75	0
Hydrogen	12–15 ^(b)	33–16	12.6	13.1	13.7	18	25	100
Oxygen	0	0	49.9	34.7	18.2	–	–	0
Specific gravity, 60° F/60° F	0.72–0.78 ^(b)	0.81–0.89 ^(d)	0.796 ^(c)	0.796 ^(c)	0.744 ^(m)	0.508	0.424	0.07 ^(u)
Density, lb/gal @ 60° F	6.0–6.5 ^(b)	6.7–7.4 ^(d)	6.63 ^(b)	6.61 ^(b)	6.19 ^(m)	4.22	1.07 ^(r)	–
Boiling temperature, °F	80–437 ^(b)	370–650 ^(d)	149 ^(c)	172 ^(c)	131 ^(c)	-44	-259	-4,230 ^(u)
Reid vapor pressure, psi	8–15 ^(k)	0.2	4.6 ^(o)	2.3 ^(o)	7.8 ^(e)	208	2,400	–
Octane no. ⁽¹⁾								
Research octane no.	90–100 ^(u)	--	107	108	116 ^(t)	112	–	130+
Motor octane no.	81–90 ^(s)	--	92	92	101 ^(t)	97	–	–
(R + M)/2	86–94 ^(s)	N/A	100	100	108 ^(t)	104	120+	–
Cetane no. ⁽¹⁾	5–20	40–55	--	--	--	--	--	--
Water solubility, @ 70° F								
Fuel in water, volume %	Negligible	Negligible	100 ^(c)	100 ^(b)	4.3 ^(e)	–	–	–
Water in fuel, volume %	Negligible	Negligible	100 ^(c)	100 ^(b)	1.4 ^(e)	–	–	–
Freezing point, °F	-40 ^(g)	-40–30 ⁽⁴⁾	-143.5	-173.2	-164 ^(c)	-305.8	-296	-435 ^(v)
Viscosity								
Centipoise @ 60° F	0.37–0.44 ^(3,p)	2.6–4.1	0.59 ^(j)	1.19 ^(j)	0.35 ^(j)	–	–	–
Flash point, closed cup, °F	-45 ^(b)	165 ^(d)	52 ^(o)	55 ^(o)	-14 ^(e)	-100 to -150	-300	--
Autoignition temperature, °F	495 ^(b)	≈600	867 ^(b)	793 ^(b)	815 ^(e)	850–950	1,004	1,050–1,080 ^(u)
Flammability limits, volume %								
Lower	1.4 ^(b)	1	7.3 ^(o)	4.3 ^(o)	1.6 ^(e,k)	2.2	5.3	4.1 ^(u)
Higher	7.6 ^(b)	6	36 ^(o)	19 ^(o)	8.4 ^(e,k)	9.5	15	74 ^(u)
Latent heat of vaporization								
Btu/gal @ 60° F	≈900 ^(b)	≈700	3,340 ^(b)	2,378 ^(b)	863 ⁽⁵⁾	775	–	–
Btu/lb @ 60° F	≈150 ^(b)	≈100	506 ^(b)	396 ^(b)	138 ⁽⁵⁾	193.1	219	192.1 ^(v)
Btu/lb air for stoichiometric mixture @ 60° F	≈10 ^(b)	≈8	78.4 ^(b)	44 ^(b)	11.8	–	–	–

Property	Gasoline	No. 2 Diesel Fuel	Methanol	Ethanol	MTBE	Propane	Compressed Natural Gas (CNG)	Hydrogen
Heating value (2)								
Higher (liquid fuel-liquid water) Btu/lb	18,800–20,400	19,200–20000	9,750 ⁽²⁾	12,800 ^(q)	18,290 ^(h)	21,600	23,600	61,002 ^(v)
Lower (liquid fuel-water vapor) Btu/lb	18,000–19,000	18,000–19,000	8,570 ^(b)	11,500 ^(q)	15,100 ^(h)	19,800	21,300	51,532 ^(v)
Higher (liquid fuel-liquid water) Btu/gal	124,800	138,700	64,250	84,100	–	91,300	–	–
Lower (liquid fuel-water vapor) Btu/gal @ 60° F	115,000	128,400	56,800 ⁽³⁾	76,000 ⁽³⁾	93,500 ⁽⁴⁾	84,500	19,800 ⁽⁶⁾	–
Heating value, stoichiometric mixture								
Mixture in vapor state, Btu/cubic foot @ 68° F	95.2 ^(b)	96.9 ^(5,q)	92.5 ^(b)	92.9 ^(b)	–	–	–	–
Fuel in liquid state, Btu/lb or air	1,290 ^(b)	–	1,330 ^(b)	1,280 ^(b)	–	–	–	–
Specific heat, Btu/lb °F	0.48 ^(g)	0.43	0.6 ^(j)	0.57 ⁽ⁱ⁾	0.5 ⁽ⁱ⁾	--	--	--
Stoichiometric air/fuel, weight	14.7 ⁽³⁾	14.7	6.45 ^(l)	9 ^(l)	11.7 ^(j)	15.7	17.2	34.3 ^(u)
Volume % fuel in vaporized stoichiometric mixture	2 ^(b)	–	12.3 ^(b)	6.5 ^(b)	2.7 ^(j)	–	–	–

Notes:

- (1) Octane values are for pure components. Laboratory engine Research and Motor octane rating procedures are not suitable for use with neat oxygenates. Octane values obtained by these methods are not useful in determining knock-limited compression ratios for vehicles operating on neat oxygenates and do not represent octane performance of oxygenates when blended with hydrocarbons. Similar problems exist for cetane rating procedures.
- (2) The higher heating value is cited for completeness only. Since no vehicles in use, or currently being developed for future use, have powerplants capable of condensing the moisture of combustion, the lower heating value should be used for practical comparisons between fuels.
- (3) Calculated.
- (4) Pour Point, ASTM D 97 from Reference (c).
- (5) Based on cetane.
- (6) For compressed gas at 2,400 psi.

Sources:

- (a) The basis of this table and associated references was taken from: American Petroleum Institute (API), Alcohols and Ethers, Publication No. 4261, 2nd ed. (Washington, DC, July 1988), Table B-1.
- (b) "Alcohols: A Technical Assessment of Their Application as Motor Fuels," API Publication No. 4261, July 1976.
- (c) Handbook of Chemistry and Physics, 62nd Edition, 1981, The Chemical Rubber Company Press, Inc.
- (d) "Diesel Fuel Oils, 1987," Petroleum Product Surveys, National Institute for Petroleum and Energy Research, October 1987.
- (e) ARCO Chemical Company, 1987.
- (f) "MTBE, Evaluation as a High Octane Blending Component for Unleaded Gasoline," Johnson, R.T., Taniguchi, B.Y., Symposium on Octane in the 1980's, American Chemical Society, Miami Beach Meeting, September 10-15, 1979.

- (g) "Status of Alcohol Fuels Utilization Technology for Highway Transportation: A 1981 Perspective," Vol. 1, Spark-Ignition Engine, May 1982, DOE/CE-56051-7.
- (h) American Petroleum Institute Research Project 44, NBS C-461.
- (i) Lang's Handbook of Chemistry, 13th Edition, McGraw-Hill Book Company, New York, 1985.
- (j) "Data Compilation Tables of Properties of Pure Compounds," Design Institute for Physical Property Data, American Institute of Chemical Engineers, New York, 1984.
- (k) Petroleum Product Surveys, Motor Gasoline, Summer 1986, Winter 1986/1987, National Institute for Petroleum and Energy Research.
- (l) Based on isooctane.
- (m) API Monograph Series, Publication 723, "Tertiary-Butyl Methyl Ether," 1984.
- (n) BP America, Sohio Oil Broadway Laboratory.
- (o) API Technical Data Book – Petroleum Refining, Volume I, Chapter I. Revised Chapter 1 to First, Second, Third and Fourth Editions, 1988.
- (p) "Automotive Gasolines," SAE Recommended Practice, J312 May 1986, 1988 SAE Handbook, Volume 3.
- (q) "Internal Combustion Engines and Air Pollution," Obert, E.F., 3rd Edition, Intext Educational Publishers, 1973.
- (r) Value at 80 degrees F with respect to the water at 60 degrees F (Mueller & Associates).
- (s) National Institute for Petroleum and Energy Research, Petroleum Product Surveys, Motor Gasolines, Summer 1992, NIPER-178 PPS 93/1 (Bartlesville, OK, January 1993), Table 1.
- (t) P. Dorn, A.M. Mourao, and S. Herbstman, "The Properties and Performance of Modern Automotive Fuels," Society of Automotive Engineers (SAE), Publication No. 861178 (Warrendale, PA, 1986), p. 53.
- (u) C. Borusbay and T. Nejat Veziroglu, "Hydrogen as a Fuel for Spark Ignition Engines," Alternative Energy Sources VIII, Volume 2, Research and Development (New York: Hemisphere Publishing Corporation, 1989), pp. 559-560.
- (v) Technical Data Book, Prepared by Gulf Research and Development Company, Pittsburgh, PA, 1962.

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APPENDIX B

Current LMOP Landfill and Gas Utilization Project Database - Texas

Senate District	Landfill Name	Landfill City	Landfill County	WIP (tons)	Year Landfill Opened	Landfill Closure Year	Landfill Owner	Project Status	Status	Project Start Date	Project Developer	Specific Utilization Type	Utilization Type	LFG Flow (mms cfd)	LFG Flared (cfm)
1	Pine Hill LF	Longview	Gregg	11,250,000	1982	2010	Allied Waste Industries	Potential	Candidate			Unknown	Direct		0
1	Green Hill Farms LF	Tyler	Smith			2007	Mobley Corporation	DUPLICATE				Unknown	Direct		0
1	Greenwood Farms	Tyler	Smith	2,247,294	1988	2001	Allied Waste Industries	Unknown				Unknown	Direct		0
2	Laidlaw/Wilmer LF	Wilmer	Dallas	686,400	1992	2001	Laidlaw Waste Systems (Dallas)	Unknown				Unknown	Direct		0
2	Pecan Prairie Landfill	Kingston					WMI	Planned		01/01		Reciprocating Engine	Electricity		0
2	Greenville Landfill	Kingston	Hunt	1,479,894	1984	1998		Unknown				Unknown	Direct		0
2	Castle Road Landfill	Garland	Dallas	3,858,050	1978	2002	City of Garland	Operational	Current	05/01	U.S. Energy Biogas Corp.	Direct Thermal	Direct	1.1	0
2	Mesquite Sanitary Landfill	Dallas	Dallas	4,692,025	1977	2076	Allied Waste Industries, Inc.	Potential	Candidate			Unknown	Direct		0
3	Royal Oaks	Jacksonville	Cherokee	720,000	1983	2030	Allied Waste Industries	Potential				Unknown	Direct		0
3	City Of Nacogdoches	Nacogdoches	Nacogdoches	1,064,534	1977	2033	City of Nacogdoches	Unknown				Unknown	Direct		0
3	Security Recycling and Disposal LF	Security	Montgomery	572,000	1992	2001	WMI	Construction	Current	01/01	Reliant Energy	Reciprocating Engine	Electricity		0
3	City of Conroe LF	Conroe	Montgomery	3,146,000	1975	2001	WMI	Construction	Current	01/01	Reliant Energy	Reciprocating Engine	Electricity		0
3	Waste Management Of Texas, Inc.-g	Cut-N-Shoot	Montgomery	2,005,452	1985			Unknown				Unknown	Direct		0
4	Beaumont LF	Beaumont	Jefferson	1,123,882	1991	2001	Allied Waste Industries	Unknown				Unknown	Direct		0
4	City of Conroe LF/Western Waste (D)	Conroe	Montgomery	629,200	1993	2001	Western Waste Industries Incorporated	DUPLICATE				Unknown	Direct		0
4	City of Conroe LF/Western Waste (C)	Conroe	Montgomery	572,000	1993	2001	Western Waste Industries of Texas	DUPLICATE				Unknown	Direct		0

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4	Sanifill Of Texas-Baytown LF	Baytown	Chambers	5,142,461	1983	2013	Waste Management of TX	Construction	Current		Reliant Energy	Reciprocating Engine	Electricity		0
4	City of Conroe LF/Western Waste (B)	Conroe	Montgomery	1,859,000	1983	1996	City of Conroe	DUPLICATE				Unknown	Direct		0
4	City of Beaumont LF	Beaumont	Jefferson	2,251,245	1983	2021	City of Beaumont	Unknown				Unknown	Direct		0
5	Brazos Valley Swma	Byan & College Station	Brazos	1,980,000	1981	2005	Brazos Valley SWMA	Unknown				Unknown	Direct		0
5	Williamson County	Hutto	Williamson	1,516,800	1981	2001	WMI	Planned	Candidate	01/01		Reciprocating Engine	Electricity		0
6	Blue Bonnet LF	Houston	Harris				WMI	Construction	Current	01/01	Reliant Energy	Reciprocating Engine	Electricity		0
6	McCarty Road LF	Houston	Harris	28,918,718	1977	2001	Allied Waste Industries	Operational	Current	01/01	GSF Energy	High Btu	Direct	8.0	5900
8	North Texas Waste/Maxwell Creek LF	Plano	Collin	6,064,067	1975	2001	North Texas Municipal Water District	Unknown				Unknown	Direct		0
8	City of McKinney LF	McKinney	Collin	1,626,644	1980	2005	City of McKinney	Unknown				Unknown	Direct		0
9	City Of Irving	Irving	Dallas	1,800,000	1981	2051	City of Irving	Unknown				Unknown	Direct		0
9	City of Farmers Branch LF	Hebron	Denton	4,381,844	1981	2041	City of Farmers Branch	Unknown				Unknown	Direct		0
9	City of Irving LF	Irving	Dallas	261,690	1994	1995	City of Irving	DUPLICATE				Unknown	Direct		0
9	City of Grand Prairie LF	Grand Prairie	Dallas	2,098,584	1977	2021	City of Grand Prairie	Planned	Candidate	01/01		Unknown	Direct	3.6	0
10	City of Fort Worth LF	Fort Worth	Tarrant	4,996,994	1976	2016	City of Fort Worth	Planned	Candidate	01/01		Direct Thermal	Direct	2.5	0
10	Arlington LF	Arlington	Tarrant	13,981,144	1978	2008	City of Arlington	Operational	Current	01/01	Renovar Energy Corp.	Medium Btu	Direct	1.8	0
11	Coastal Plains LF	Alvin	Galveston	2,689,200	1985	2001	WMI	Construction	Current	01/01	Reliant Energy	Reciprocating Engine	Electricity		0
11	WMI/E & D Waste Systems Inc. LF	Alvin	Galveston	858,000	1994	2001	Waste Management of Texas, Incorporated	Unknown				Unknown	Direct		0

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11	Brazoria County Disposal LF	Angleton	Brazoria	3,919,000	1993	2050	WMI	Unknown				Unknown	Direct		0
11	Galveston County LF	Galveston	Galveston	6,618,319	1973	2025	Allied Waste Industries	Unknown				Unknown	Direct		0
12	City Of Denton	Denton	Denton	2,000,000	1985	2024	City of Denton	Unknown				Unknown	Direct		0
12	Eastside Landfill	Fort Worth					WMI	Planned		01/01		Reciprocating Engine	Electricity		0
13	Blue Ridge LF	Houston	Fort Bend	1,910,676	1993	2025	Allied Waste Industries	Unknown				Unknown	Direct		0
13	WMI/Atascocita LF	Humble	Harris	6,049,524	1993	2016	Waste Management of Texas, Incorporated	Construction	Current	01/01	Reliant Energy	Reciprocating Engine	Electricity		0
14	Austin Community LF	Austin	Travis	8,080,500	1977	2001	WMI	Operational	Current	01/01	Toro Energy	Unknown	Direct	1.1	0
14	City of Austin (II) LF	Elroy	Travis			2027		Unknown				Unknown	Direct		0
14	Steinar LF	Elroy	Travis			2027	T.C. Steiner	Unknown				Unknown	Direct		0
14	City Of Austin LF	Austin	Travis	4,734,096	1977	2002	City Of Austin	Unknown		01/01		Reciprocating Engine	Electricity		0
14	Sunset Farms-Austin LF	Austin	Travis	2,845,301	1981	2031	Allied Waste Industries	Operational	Current	01/01	GRS	Reciprocating Engine	Electricity	2.2	850
14	Texas Disposal Systems LF	Austin	Travis	2,043,245	1990	2050	Texas Disposal Systems	Unknown				Unknown	Direct		0
15	Whispering Pines LF	Houston	Harris	6,005,991	1978	2017	Allied Waste Industries	Planned	Candidate	11/01		Reciprocating Engine	Electricity		0
17	Sprint Fort Bend County LF	Houston	Fort Bend	1,664,372	1981	2020	Sprint Fort Bend County	Unknown				Unknown	Direct		0
17	Sprint LF	Sugarland	Harris	1,716,000	1987	2001	Laidlaw Waste Systems Inc.	Unknown				Unknown	Direct		0
17	City Of Port Arthur	Port Arthur	Jefferson	1,516,481	1986	2044	City of Port Arthur	Unknown				Unknown	Direct		0
18	Laidlaw Environmental SLF	Columbus	Colorado	9,009,000	1988	1997		Unknown				Unknown	Direct		0

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18	City Of Victoria	Bloomington	Victoria	2,280,369	1982	2040	City of Victoria	Unknown				Unknown	Direct		0
18	Tricil Environmental Response/Altair SLF	Altair	Colorado	1,841,556	1976	2002	Safety Clean (formerly Laidlaw)	Unknown				Unknown	Direct		0
18	Best Pak Disposal Inc. LF	Pattison	Waller			2001	Best Pak Disposal Incorporated	Unknown				Unknown	Direct		0
19	Clint LF	Clint	El Paso	4,185,278	1983	2006	City of El Paso	Unknown				Unknown	Direct		0
19	Garbage Gobbler/Covel Gardens LF	San Antonio	Bexar	3,728,209	1991	2004	WMI	Planned	Candidate			Unknown	Direct	9.4	0
20	CNT Regional LF	Linn	Hidalgo	2,519,400	1976	2004	R.E. Wolfe Enterprises	Unknown				Unknown	Direct		0
20	J.C. Elliot LF	Corpus Christi	Nueces	6,000,000	1972	2000	City of Corpus Christi	Construction	Current		Resource Technology Corporation	High Btu	Direct		0
21	Sanifill/Crow LF	Lakeside	Tarrant	2,303,364	1976		Sanifill of Texas Incorporated	Unknown				Unknown	Direct		0
21	BFI/Tessman Road LF	San Antonio	Bexar			2003		DUPLICATE				Unknown	Direct		0
21	City of Laredo LF	Laredo	Webb	2,273,083	1986	2015	City of Laredo	Potential	Candidate			Medium Btu	Direct		0
21	Tessman Road LF	San Antonio	Bexar	9,337,518	1981	2005	Allied Waste Industries	Planned	Candidate	05/01		Reciprocating Engine	Electricity	1.8	0
22	CSC Disposal LF	Avalon	Ellis	4,254,250	1985	2047	CSC Disposal & Landfill Inc.	Unknown				Unknown	Direct		0
22	City of Waco LF #2	Waco	McLennan			2001	Neeley Sand and Gravel Incorporated	DUPLICATE				Unknown	Direct		0
22	Ellis County LF	Palmer	Aransas	892,320	1994		WMI	Unknown				Unknown	Direct		0
22	City of Corsicana LF	Corsicana	Navarro	343,200	1993	2001		Unknown				Unknown	Direct		0
22	Skyline LF	Ferris	Ellis	28,200,000	1987	2040	WMI	Potential	Candidate			Unknown	Direct		970
22	Lacy-Lakeview LF	Waco	McLennan	936,358	1985	2001	WMI	Planned		01/01		Reciprocating Engine	Electricity		0

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22	City of Waco LF #1	Woodway	McLennan	2,799,000	1987	2001	City of Waco	Unknown				Unknown	Direct		0
22	City Of Cleburne	Cleburne	Johnson	1,512,000	1976			Unknown				Unknown	Direct		0
22	Turkey Creek LF	Alvarado	Johnson	2,324,631	1983	2001	Allied Waste Industries	Planned	Candidate	01/01		Unknown	Direct	1.0	0
23	Hutchins Landfill	Hutchins		1,000,000			Allied Waste Industries	Planned		11/01		Reciprocating Engine	Electricity		0
23	McCommas Bluff LF/City of Dallas	Dallas	Dallas	20,000,000	1980	2053	City of Dallas	Operational	Current	01/01	Pacific Natural Energy LLC	High Btu	Direct	9.4	0
24	City of Brownwood Landfill	Brownwood	Brown	1,000,000	1996	2040	City of Brownwood	Operational	Current	01/01	Fenn Tech	Leachate Evaporation	Direct	0.4	0
24	City of Temple Landfill	Temple					City of Temple	Planned		01/01		Reciprocating Engine	Electricity		0
24	Bell County/Sparks LF	Belton	Bell	343,200	1994	2001	Bell County	Unknown				Unknown	Direct		0
24	BFI LF	Abilene	Taylor	745,888	1993	2001	Pine Street Salvage Company	Unknown				Unknown	Direct		0
25	Comal County LF	New Braunfels	Comal	3,060,723	1975	2011	WMI	Planned	Candidate	01/01		Reciprocating Engine	Electricity	1.3	0
28	Colorado City Landfill	Colorado City	Mitchell	1,528,956	1975	2020	City of Colorado	Unknown				Unknown	Direct		0
28	City Of Sweetwater LF	Sweetwater	Nolan	1,262,948	1976	2040	City of Sweetwater	Unknown				Unknown	Direct		0
28	BFI/Quail Canyon LF	Lubbock	Lubbock	200,200	1993	1994	Allied Waste Industries	Unknown				Unknown	Direct		0
28	City of Pampa LF	Pampa	Gray	1,157,820	1975	2007	City of Pampa	Unknown				Unknown	Direct		0
28	City of Lubbock LF	Lubbock	Lubbock	1,629,232	1975	2008	City of Lubbock	Unknown				Unknown	Direct		0
28	Abilene Regional LF	Abilene	Jones	7,020,000	1982	2067	Allied Waste Industries	Unknown				Unknown	Direct		0
29	McCombs LF	El Paso	El Paso	3,653,342	1984	2046	City of El Paso	Unknown				Unknown	Direct		0
30	Westside LF/Fort Worth Regional LF	Fort Worth	Parker	1,823,250	1994	2007	Waste Management Inc	Potential	Candidate			Unknown	Direct		0
30	Bell Processing Inc. LF	Wichita Falls	Wichita		1990	2001	Bell Processing Inc	Unknown				Unknown	Direct		0
30	Hillside Landfill	Sherman	Grayson	2,008,657	1981	2023	WMI	Planned	Candidate	01/01		Reciprocating Engine	Electricity		0

Current LMOP Landfill and Gas Utilization Project Database - Texas

Senate District	Landfill Name	Landfill City	Landfill County	WIP (tons)	Year Landfill Opened	Landfill Closure Year	Landfill Owner	Project Status	Status	Project Start Date	Project Developer	Specific Utilization Type	Utilization Type	LFG Flow (mms cfd)	LFG Flared (cfm)
30	Westside Sanitary LF	Aledo	Tarrant				Waste Management of Texas, Incorporated	Potential				Unknown	Direct		0
30	City Of Weatherford LF	Weatherford	Parker	1,016,400	1976	2060	City of Weatherford	Unknown				Unknown	Direct		0
30	City of Wichita Falls LF	Wichita Falls	Wichita	3,495,847	1982	2021	City of Wichita	Unknown				Unknown	Direct		0
30	Wichita Falls LF	Wichita Falls	Wichita			2001	City of Wichita Falls	DUPLICATE				Unknown	Direct		0
31	Southwest LF	Canyon	Randall	2,760,000	1987	2025	Allied Waste Industries	Unknown				Unknown	Direct		0
31	City Of Midland LF	Midland	Midland	2,620,672	1990	2021	City of Midland	Unknown				Direct Thermal	Direct		0
31	City Of Perryton	Perryton	Ochiltree	1,606,966	1979	2006	City of Perryton	Unknown				Unknown	Direct		0
31	Amarillo LF	Amarillo	Potter	6,132,600	1976	2050	City of Amarillo	Unknown				Unknown	Direct		0
not known	Rosenberg Landfill	Rosenberg	Fort Bend	1,000,000	1978	1993	Fort Bend County	Operational	Current	01/01	Pacific Natural Energy LLC	Direct Thermal	Direct	1.1	0
not known	Dallas-Fort Worth LF	Dallas	Denton	15,000,000	1980	2025	WMI	Operational	Current	01/01	Bio Energy Partners	Gas Turbine	Electricity	2.1	0

Project Status	Number of Facilities Meeting That Status
Construction	7
Operational	9
Planned	14
Potential	7
Unknown	52
Duplicate	8

Specific Utilization Type	Number of Facilities Of That Utilization Type
Direct Thermal	4
Gas Turbine	1
High Btu	3
Leachate Evaporation	1
Medium Btu	2
Reciprocating Engine	18
Unknown	68